International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 22 No. 2(2) (2026)

ijerst.editor@gmail.com

editor@ijerst.com

International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
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Peer Reviewed, Referred & Indexed Journal

Research Paper

Dynamic Field-Coupled Energy Delivery System for Uninterrupted Electric Vehicle Propulsion

B. Ravi kumar[1*], K. Shinu[1], T. Sameera[1], P. Nageswari[1], K Kiranmai[1]

[1]Department of Electronics and Communication Engineering, Mother Teresa Institute of Science and Technology, Sanketika Nagar, Kothuru, Sathupally, Khammam, 507303, Telangana, India

*Correspondence: B. Ravi kumar

Abstract

Electric vehicles are rapidly gaining attention as a sustainable alternative to conventional transportation, yet their widespread adoption is still limited by challenges such as restricted driving range and long charging times. To address these issues, this work proposes an embedded IoT-based system that enables wireless charging of vehicles while they are in motion. By utilizing dynamic wireless power transfer, the system allows continuous and contactless energy delivery, reducing dependency on stationary charging infrastructure. The design is composed of two coordinated units: a transmitter integrated into the road surface and a receiver mounted on the vehicle. The transmitter unit, controlled by an ESP32 microcontroller, generates a high-frequency electromagnetic field through strategically placed coil segments. These segments are activated only when a vehicle is detected above them, with the help of a positioning mechanism that ensures efficient power transfer. An LCD interface provides real-time system monitoring. On the vehicle side, the receiver unit uses an Arduino Uno to manage energy collection through multiple coils placed beneath the chassis. Infrared sensors assist in detecting vehicle position and aligning the coils for optimal energy reception, after which the captured energy is regulated and used to charge the battery. This coordinated operation enhances energy efficiency by minimizing power wastage and supports uninterrupted vehicle operation. The system contributes toward the development of intelligent transportation infrastructure and offers a practical step toward continuous, on-the-move charging for electric vehicles.

Keywords: Wireless Power Transfer, Dynamic Charging, Electric Vehicle, Arduino Uno, TX Coil, RX Coil, IR Sensor, Contactless Energy Transfer, Range Anxiety.

1. Introduction

The transition toward electric mobility has accelerated in recent years due to growing environmental concerns and the need to reduce reliance on conventional fossil fuels. Even though electric vehicles offer a cleaner alternative, their practical usage is often limited by charging constraints and dependency on fixed charging stations. Long charging durations and limited availability of infrastructure create inconvenience for users, especially during long-distance travel. These limitations highlight the need for more flexible and efficient charging solutions that can seamlessly integrate with everyday transportation. An emerging approach to overcome these challenges is the concept of in-motion wireless energy transfer for electric vehicles. Instead of relying on plug-in charging, this method enables vehicles to receive power directly from specially equipped roadways while they are moving. The technology operates through electromagnetic coupling, where energy is transmitted from coils embedded beneath the road to corresponding coils installed underneath the vehicle. As the vehicle travels across these sections, electrical energy is transferred continuously, supporting battery charging without interrupting the journey. The system involves a combination of embedded road infrastructure and onboard vehicle components that work together to facilitate energy transfer. Power supplied from the grid is converted into a suitable form and transmitted through road-integrated modules, generating a magnetic field that

can be captured by the vehicle's receiving unit. The received energy is then conditioned and directed to recharge the vehicle battery in real time.

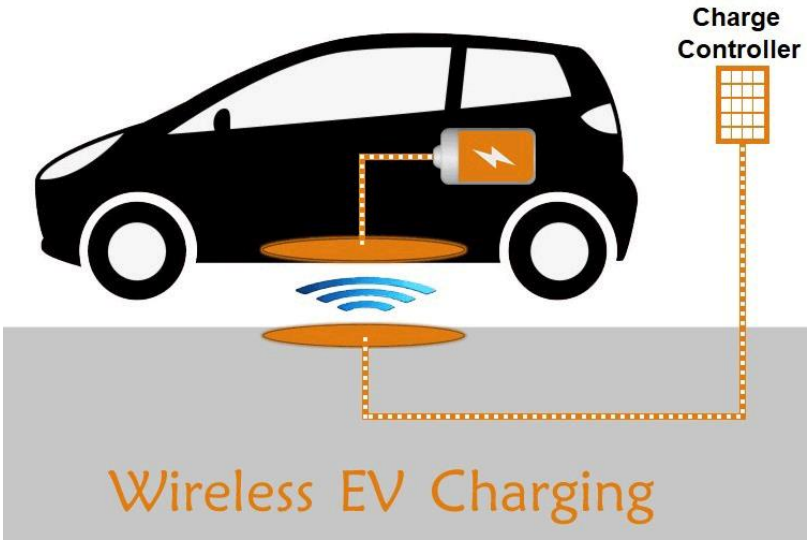

Figure. 1: Smart on road charging

This coordinated mechanism enables efficient power delivery while maintaining minimal user intervention. Such a system offers several benefits, including reduced dependency on large battery capacities and improved driving convenience. Continuous charging capability helps extend vehicle range and supports smoother transportation flow. At the same time, this approach encourages wider adoption of electric vehicles by addressing key usability concerns. However, practical implementation requires overcoming technical and economic barriers. Challenges such as infrastructure investment, power transfer efficiency, system alignment, and safety considerations must be carefully addressed. Ongoing advancements in electronics, communication systems, and intelligent monitoring are expected to play a crucial role in making this technology more reliable and scalable.

2. Literature Survey

S. Li and C. C. Mi et al. [1] discussed wireless power transfer systems for electric vehicles by focusing on how inductive and resonant coupling methods can be effectively used in real-world applications. Their work explains how the arrangement and shape of coils play a major role in determining how efficiently power is transferred between the road and the vehicle. They also describe different compensation techniques that help maintain stable power flow under varying conditions. The integration of power electronic components is explained in a way that highlights their importance in controlling voltage and current levels. Attention is given to how systems can maintain performance even when there is slight misalignment between transmitter and receiver coils. Safety aspects, such as electromagnetic exposure and system protection, are also carefully addressed. The discussion further explores how efficiency can be improved by optimizing circuit parameters. Practical implementation challenges are indirectly highlighted through design considerations. Their contribution provides a strong technical base for building reliable wireless charging systems.

A. Kurs, et al. [2] introduced the concept of magnetic resonance as a powerful technique for transferring energy wirelessly over moderate distances. Their work explains how energy can be exchanged between two objects that are tuned to resonate at the same frequency. This concept is demonstrated using experimental setups that show energy transfer without direct contact. The explanation of non-radiative energy transfer makes the concept easier to understand in practical terms. The ability to achieve efficient transfer over distances greater than traditional inductive methods is emphasized. Their findings highlight how resonance improves coupling between coils even when they are not very close. The work also explains how losses can be minimized by maintaining proper frequency tuning. This approach opened new possibilities for applications beyond short-range charging. The idea has since become a

key principle in modern wireless charging systems. Their contribution is widely recognized as a turning point in wireless power technology.

B. L. Cannon, et al. [3] explored how wireless power systems can be extended to support multiple receiving units from a single transmitting source. Their explanation focuses on how resonance can be used to distribute energy efficiently across several devices. The concept of tuning multiple receivers to the same frequency is described as a way to ensure consistent power delivery. Their work shows that energy sharing can be achieved without significantly reducing efficiency. The importance of system scalability is clearly highlighted in their discussion. They also explain how coil placement and system design influence performance in multi-receiver environments. The challenges of maintaining stable operation when multiple loads are connected are addressed. Their findings suggest that proper system tuning is essential for balanced power distribution. This idea is especially useful for applications involving multiple charging points. Their contribution supports the development of flexible and scalable wireless charging systems. International Energy Agency (IEA) [4] provided detailed insights into the global growth of electric vehicles and the increasing demand for efficient charging solutions. Their report explains how the rising number of EVs is creating pressure on existing infrastructure. It highlights the limitations of conventional charging methods in meeting future demands. The importance of developing advanced charging technologies is strongly emphasized. Their discussion includes how user convenience plays a key role in technology adoption. The need for faster and more accessible charging options is clearly presented. They also address how infrastructure planning must adapt to support large-scale deployment. Environmental benefits of EV adoption are linked with improved charging solutions. The report indirectly encourages the development of innovative systems like wireless charging. Their observations provide a broader context for why new charging methods are necessary.

J. M. Miller et al. [5] described various wireless power transfer techniques used in both electric vehicles and portable electronic devices. Their explanation covers different methods such as inductive and resonant coupling in a clear and structured manner. The role of system components like coils and converters is explained in practical terms. They also discuss how power electronics are used to manage energy flow efficiently. The importance of system design in achieving high performance is highlighted throughout. Their work explains common challenges such as energy loss and system inefficiency. The relationship between frequency, coil design, and power transfer is clearly described. Implementation constraints are presented in a way that reflects real-world conditions. Their discussion helps in understanding how theoretical concepts are applied in practice. This contribution serves as a strong technical reference for system design.

H. H. Wu, et al. [6] explained different approaches to wireless charging, including stationary, partially dynamic, and fully dynamic systems. Their discussion highlights how each method differs in terms of operation and practicality. The benefits of allowing vehicles to charge while moving are clearly emphasized. They describe how alignment between coils affects system efficiency. The complexity of infrastructure required for dynamic charging is also discussed. Their explanation includes how energy transfer can be maintained over longer distances. Challenges such as system cost and installation difficulty are indirectly presented. The advantages of improved convenience and reduced charging interruptions are highlighted. Their work suggests that dynamic charging can significantly improve user experience. This contribution helps in understanding the evolution of wireless charging systems. SAE International [7] introduced a standardized framework for wireless charging systems used in electric vehicles. Their guidelines define important parameters such as operating frequency and power levels. The importance of safety regulations is clearly emphasized throughout their work. They explain how standardization ensures compatibility between different systems. The role of interoperability in large-scale deployment is also highlighted. Their framework helps manufacturers design systems that meet common requirements. The discussion includes how consistent performance can be achieved across different platforms. They also address how safety concerns can be minimized through proper design.

Their contribution supports the development of reliable and uniform charging systems. This standard plays a crucial role in the practical implementation of wireless charging technology.

Y. Zhang, et al. [8] focused on improving the performance of wireless charging systems through better design techniques. Their explanation highlights how coil structure affects energy transfer efficiency. They describe how compensation networks can be used to stabilize system performance. The importance of optimizing system parameters is clearly presented. Their work explains how energy losses can be reduced through proper design. The relationship between system components and overall efficiency is discussed in detail. They also highlight how performance can vary under different operating conditions. Their findings show that careful tuning leads to better results. The role of engineering design in improving system reliability is emphasized. This contribution provides useful insights into system optimization.

T. Imura and Y. Hori [9] explained how the distance between transmitter and receiver coils can be increased without reducing efficiency. Their work focuses on improving system performance through resonance tuning. They describe how proper frequency adjustment enhances energy transfer. The importance of maintaining system stability under different conditions is highlighted. Their explanation shows how air gap variations affect performance. They also discuss how efficiency can be preserved despite physical separation. Their findings highlight the importance of circuit design in achieving better results. The relationship between resonance and power transfer is clearly explained. Their contribution supports the development of practical charging systems. This work is especially relevant for real-world applications where perfect alignment is not always possible. World Economic Forum [10] discussed the development of electric vehicle infrastructure from a global perspective. Their explanation highlights the importance of adopting advanced charging technologies. The need for scalable solutions to support increasing EV demand is clearly presented. They emphasize how user convenience influences technology adoption. The discussion includes how wireless charging can simplify the charging process. Environmental benefits are linked with improved infrastructure development. They also highlight the importance of innovation in transportation systems. Their observations suggest that future systems must be efficient and user-friendly. The role of policy and planning in technology adoption is indirectly addressed. This contribution provides a broader understanding of the future direction of EV charging systems.

3. Proposed System

The designed system introduces a smart wireless charging approach that allows electric vehicles to receive energy while moving, without requiring any physical connection. It is structured as two coordinated units: a transmitter embedded beneath the road surface and a receiver installed within the vehicle. The energy transfer takes place through magnetic induction, enabling contactless power flow between the road infrastructure and the moving vehicle. The transmitter section is controlled by an ESP32 microcontroller, which manages the generation of a high-frequency magnetic field through transmitting coils placed under the road. It also controls when and where the coils should be activated, ensuring that energy is supplied only when a vehicle is present. A display module is included to show system conditions such as operational status and charging activity, as shown in figure 2. Additionally, a positioning mechanism beneath the road ensures that the transmitting coils are properly aligned with the vehicle as it moves over them. On the vehicle side, the receiver unit is built using an Arduino Uno microcontroller that handles energy collection and regulation. Multiple receiver coils are placed under the vehicle to improve energy capture even if alignment is not perfect. Infrared sensors continuously monitor the vehicle's position and help trigger the charging process at the right moment.

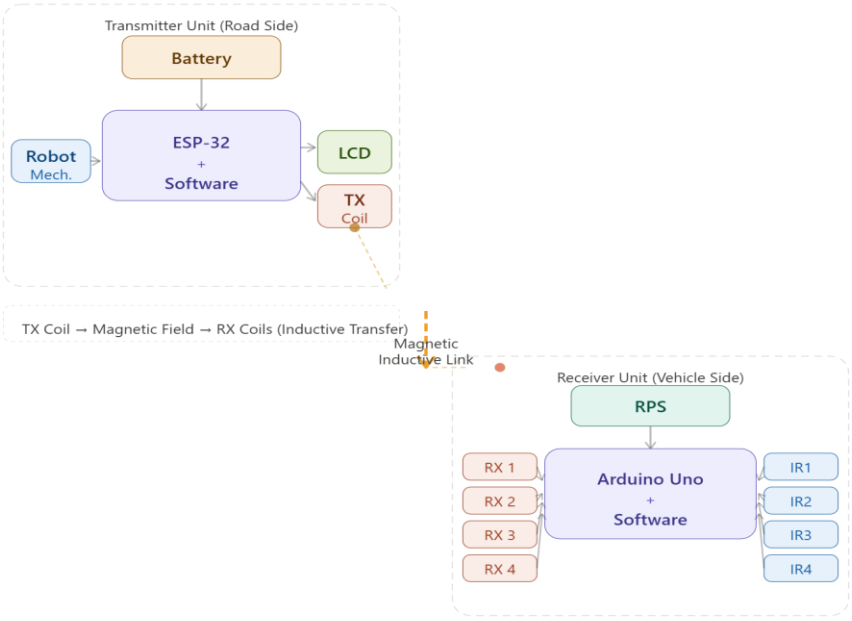

Figure. 2: System architecture.

Once energy is received, it is converted into a usable form and directed to charge the vehicle battery. The system operates only when a vehicle is detected, which helps avoid unnecessary energy loss. Its modular design allows multiple charging segments to be deployed along roadways, making it suitable for scalable implementation across longer distances.

3.1 Flow Chart

The figure 3 illustrates the internal workflow of a dynamic wireless charging system, divided into two synchronized sections: the transmitter (road side) and the receiver (vehicle side). Both units operate in coordination to enable efficient, real-time energy transfer only when a vehicle is present. The process begins with system initialization, followed by condition checks, activation of coils, and controlled power transfer. It also includes safety conditions like battery monitoring and automatic deactivation to avoid energy loss. The entire system works in a loop, ensuring continuous monitoring and adaptive response as the vehicle moves through the charging zone.

System Initialization: The process starts with initializing both the transmitter and receiver units. The ESP-32 on the road side activates components such as the TX coil, LCD, and battery system. Simultaneously, the Arduino Uno initializes RX coils, IR sensors, and power supply modules. This step ensures all hardware components are ready for operation. It also establishes baseline communication between sensing and control elements. Proper initialization is critical for synchronized system performance.

Battery and Sensor Check: The transmitter first checks whether the battery level is sufficient for operation. If the battery is low, an alert is displayed on the LCD to notify the system operator. On the receiver side, IR sensors continuously scan for vehicle presence and alignment. These sensors provide real-time positional data. This step ensures that charging only proceeds under safe and valid conditions. It also prevents unnecessary power usage.

Vehicle Detection and Alignment: Once a vehicle is detected, the system verifies whether it is within the charging zone. The IR sensors help determine proper alignment between transmitter and receiver coils. Based on this input, the system prepares for energy transfer. The robot mechanism on the transmitter side positions the TX coil accordingly. This alignment step is essential for maximizing power transfer efficiency. It reduces losses caused by misalignment.

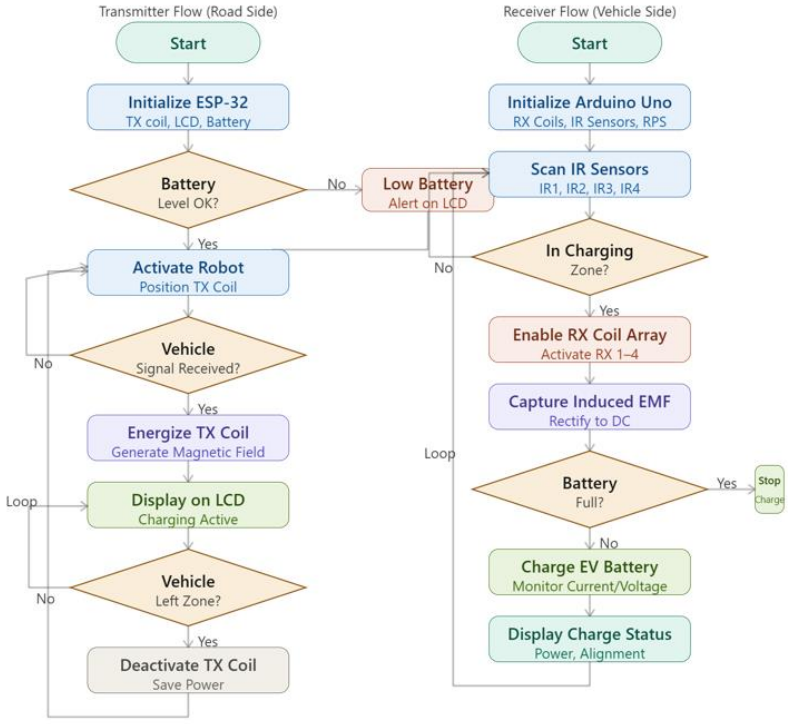

Figure. 3: Flow chart

Coil Activation and Energy Transfer: After successful detection, the transmitter energizes the TX coil to generate a magnetic field. The receiver activates its RX coil array to capture the induced electromagnetic energy. This energy is then rectified into DC form for battery charging. The process occurs in real time as the vehicle moves. Continuous monitoring ensures stable energy flow. This step forms the core of wireless power transfer.

Charging Monitoring and Display: During charging, system parameters such as power level, voltage, and alignment status are displayed. The LCD on the transmitter and display unit on the receiver provide real-time updates. The system also checks whether the vehicle battery is fully charged. If charging is complete, the process is stopped automatically. This step ensures transparency and safe operation. It also enhances user awareness.

Deactivation and Loop Continuation: When the vehicle leaves the charging zone, the transmitter coil is deactivated to conserve energy. The system then returns to monitoring mode, waiting for the next vehicle. This loop-based operation ensures continuous readiness. It minimizes idle power consumption by activating components only when required. The cycle repeats efficiently for multiple vehicles.

4. Results and Discussion

The Results and Discussion section presents the performance evaluation of the proposed wireless on-road charging system under different operating conditions. It analyzes how effectively the system enables power transfer between the transmitter and receiver units while the vehicle is in motion. Key observations include charging efficiency, alignment accuracy, and system response to real-time vehicle detection. The behavior of individual components such as coils, sensors, and controllers is examined to understand their contribution to overall performance. The discussion also highlights how the system minimizes energy loss by activating only when required. Experimental outcomes are compared with expected results to validate system reliability.

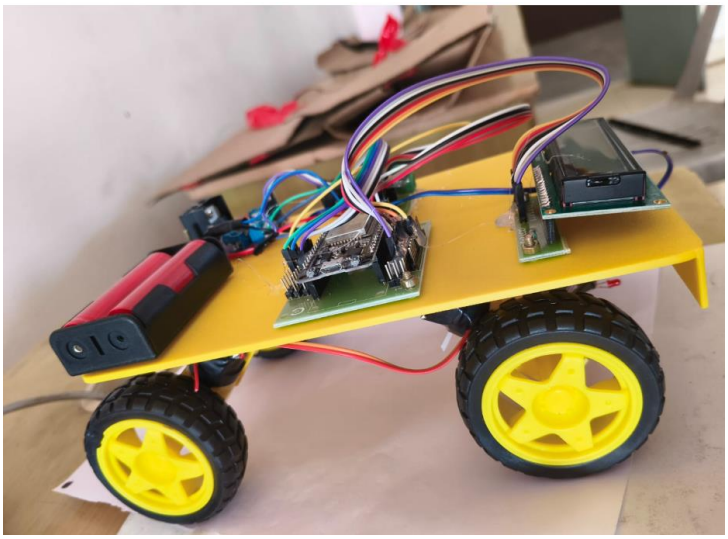

Figure. 4: Prototype model of vehicle-mounted wireless charging receiver unit

Figure 4 illustrates the developed prototype of the vehicle-side module designed for dynamic wireless power reception in an electric vehicle charging system. The setup integrates a microcontroller-based control unit that manages sensor inputs and regulates the charging process in real time. Multiple interconnected components work together to capture induced electromagnetic energy and convert it into a usable electrical form for battery charging. The configuration demonstrates coordinated interaction between sensing, control, and power conversion modules to ensure efficient operation. The arrangement reflects a compact and functional implementation suitable for experimental validation of wireless charging concepts.

Figure. 5: Real-Time charging parameter display using LCD interface

Figure 5 depicts the real-time monitoring interface used in the wireless charging system, where key electrical parameters are continuously displayed during operation. The module provides instantaneous readings of voltage, current, and state of charge, enabling effective tracking of the charging process. This visual feedback mechanism supports system transparency and allows for quick assessment of energy transfer performance. The displayed values are dynamically updated based on sensor inputs and control logic executed by the microcontroller. Such integration enhances system reliability by facilitating timely detection of variations in charging conditions.

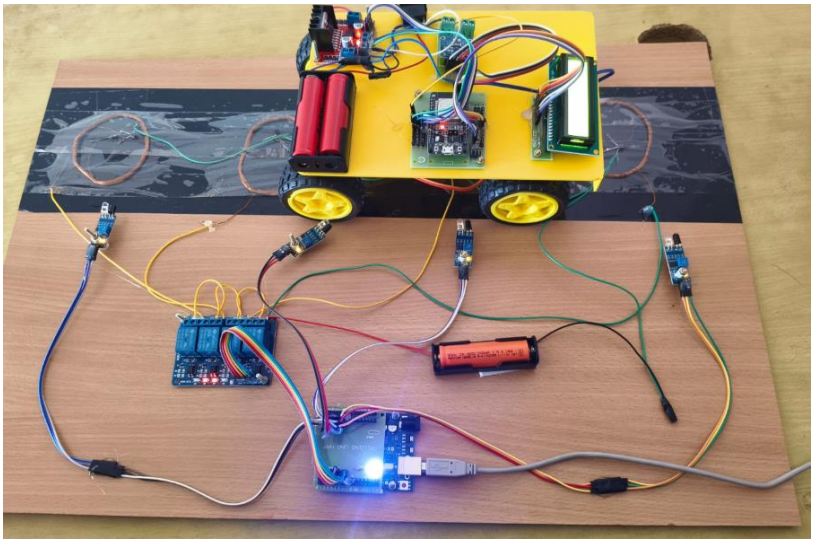

Figure. 6: Experimental setup of dynamic wireless on-Road EV charging system

Figure 6 illustrates the complete experimental implementation of the proposed wireless charging system, integrating both the road-side transmitter and vehicle-mounted receiver units. The setup demonstrates the interaction between embedded transmitting coils placed along the track and the mobile receiver system positioned on the vehicle platform. Multiple control modules and sensor interfaces are interconnected to enable real-time detection, synchronization, and energy transfer. The configuration highlights how the system activates charging segments dynamically as the vehicle moves across the defined path. Power conversion and signal coordination are managed through microcontroller-based control units, ensuring regulated energy flow. This arrangement reflects a practical validation environment used to evaluate system performance, efficiency, and operational reliability under simulated real-time conditions.

5. Conclusion

The proposed wireless on-road charging system demonstrates an effective solution for enabling continuous energy transfer to electric vehicles during motion, reducing dependency on stationary charging infrastructure. The integration of transmitter and receiver units ensures coordinated operation through real-time sensing, control, and power conversion mechanisms. The system shows improved energy utilization by activating charging segments only when a vehicle is present, thereby minimizing unnecessary power loss. The use of multiple receiver coils enhances power capture efficiency even under slight misalignment conditions. Sensor-based detection and control logic contribute to reliable and automated system performance. Experimental results indicate stable operation with consistent voltage and current output during charging. The modular architecture allows easy scalability for extended road segments. Overall, the system improves charging convenience, reduces range anxiety, and supports uninterrupted vehicle operation. Performance can be further enhanced by optimizing coil design, improving alignment techniques, and increasing power transfer efficiency. These improvements can make the system more practical for real-world deployment.

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